Post-MAP migration of crosswell seismic data

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SUMMARY

We present a method that approximately collapses diffraction events in crosswell seismic data that have been mapped using a point-to-point VSP-CDP algorithm and stacked. Our approach uses a conventional surface seismic migration algorithm with a modified velocity to compensate for the effects of VSP-CDP mapping and the crosswell geometry. The technique is approximate, and is most effective near the midpoint between the wells. As the reflection point moves toward either well, the approximations break down and the diffractions are not well collapsed. However, the diffractions are more focused with approximate migration than without. For continuous horizontal reflections, the VSP-CDP mapped section and the approximate post-MAP migration section are almost identical.

INTRODUCTION

There are two schools of thought in imaging crosswell reflection data. One approach (e.g. Goulty, 1991, Schuster, 1993) is to use prestack migration optimally collapse diffraction energy. Another approach (Lazaratos, et al, 1993) is to use a point-to-point VSP-CDP mapping algorithm (Wyatt and Wyatt, 1981). Although the VSP-CDP algorithm does not correctly handle diffraction events, it is a more benign operation in that it does not smear noise along an imaging ellipse. Since prestack crosswell reflection data are often of low signal-to-noise ratio, due to both coherent noise (tube waves, conversions, guided waves, etc.) and incoherent noise, prestack migration may not be appropriate. Prestack migration is only used in surface seismic data processing when the signal-to-noise ratio is high.

In this paper, we present a method to approximately collapse the diffractions present in the VSP-CDP mapped and stacked crosswell reflection image. This approach is similar to post-stack migration of surface seismic data. However, unlike surface reflection data, where we transform the image from unmigrated time to migrated time (or depth), we transform the crosswell data from unmigrated, but mapped depth, to (approximately) migrated depth.

THEORY

For two vertical wells, the traveltime equations for a diffractor at (X_d, Z_d) in a common middepth gather (CMG) is

$$t_{diff} = \frac{1}{v_{diff}}\left\{\sqrt{X_d^{\,2} + \left[(Z_d - M) + O\right]^2} + \sqrt{(x_w - X_d)^2 + \left[(Z_d - M) - O\right]^2}\right\}$$

where, v_{diff} is the mean ray-path velocity,

x_w is the distance between two wells,

M is the middepth $\left(\frac{Z_R + Z_S}{2}\right)$,

O is the offset $\left(\frac{Z_R - Z_S}{2}\right)$,

Z_S is the source depth,

and Z_R is the receiver depth.

If the diffractor is located midway between the two wells, the traveltime equation is

$$t_{diff} v_{diff} = \sqrt{\left(\frac{x_w}{2}\right)^2 + \left[(Z_d - M) + O\right]^2} + \sqrt{\left(\frac{x_w}{2}\right)^2 + \left[(Z_d - M) - O\right]^2} \qquad (1)$$

For small O, $t_{diff}^{\,2} v_{diff}^{\,2}$ can be approximated as

$$t_{diff}^{\,2} v_{diff}^{\,2} \approx x_w^{\,2} + 4(Z_d - M)^2 + 2O^2 \quad , \qquad (2)$$

and the squared minimum traveltime, $t^2_{diff,0}$, is

$$t^2_{diff,0} = \frac{x_w^{\,2} + 4(Z_d - M)^2}{v_{diff}^{\,2}} \quad . \qquad (3)$$

Thus,

$$t_{diff}^{\,2} = t_{diff,0}^{\,2} + \frac{2O^2}{v_{diff}^{\,2}} \quad . \qquad (4)$$

As shown by Eq. (4), the traveltime curve for a diffractor in a CMG can be approximated by a hyperbola. The caveats for this approximation are that the offsets are small and the diffraction is near the midpoint between the wells. For typical crosswell reflection incidence angles (30~70°), these caveats may be replaced by one – namely that the diffraction point is near the midpoint.

VSP-CDP transforms common middepth gathers into a mapped section (x_m, z_m) by the equations (Lazaratos, 1993):

$$x_m = \frac{x_w}{2}\left[1 + \left(\frac{2O}{\sqrt{v^2 t^2 - x_w^{\,2}}}\right)\right] \quad \text{and} \ , \qquad (5)$$

$$z_m = \frac{1}{2}\left(\sqrt{v^2 t^2 - x_w^{\,2}} + 2M\right) \quad . \qquad (6)$$

For a diffractor at the midpoint between wells, the equation of the diffractor after VSP-CDP mapping can be obtained by combining Eq. (2), (5), and (6). If only upgoing waves